Methane Emissions from Natural Gas Transmission and Storage Facilities:

Review of Available Data on Leak Emission Estimates

and Mitigation Using Leak Detection and Repair

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1.0 Introduction

For natural gas transmission and storage (T&S) facilities, methane (CH_4) emissions from leaks are regulated by the federal New Source Performance Standards (NSPS) in 40 C.F.R., Part 60, Subpart OOOOa. The NSPS includes prescribed maintenance intervals to address excess leakage from reciprocating compressor rod packing, requires a leak detection and repair (LDAR) program with quarterly surveys at T&S facilities, and requires control of the wet seal degassing vent for centrifugal compressors with wet seals. The U.S. Environmental Protection Agency (EPA) explained the basis for regulating these sources in its Technical Support Document (TSD) for the Subpart OOOOa proposed rule[1] and final rule.[2] In some cases, the associated analysis is based on older data or questionable assumptions.

This paper presents the results of two recent studies of gas leak emissions from natural gas systems, and discusses the implications of these results for LDAR provisions and natural gas compressor leak rates and/or control requirements in two Federal standards:

• 40 C.F.R. 60, Subpart OOOOa, "Standards of Performance for Crude Oil and Natural Gas Facilities for which Construction, Modification or Reconstruction Commenced After September 18, 2015," which regulates fugitive emissions (i.e., gas leaks) from oil and natural gas systems.

• 40 C.F.R. 98, Mandatory Greenhouse Gas Reporting, Subpart W, "Petroleum and Natural Gas Systems," which requires the reporting of facility greenhouse gas emissions, including those based on periodic gas leak detection surveys and the measurement of leaks rates from major compressor components (i.e., potential large leak sources).

The two recent studies include: (1) a Pipeline Research Council International (PRCI) report[3] that analyzes thousands of Subpart W annual component leak detection surveys and leak rate measurements for major compressor components conducted at natural gas T&S facilities from 2011 - 2016; and (2) a recent California Air Resources Board (CARB) leak study[4] that measured EPA Method 21 screening values (SVs) and mass emission rates from leaking components (e.g., valves, connectors) in natural gas service. The CARB study developed correlation equations for the different component types, with the correlations providing the average leak rate for the component type as a function of the Method 21 SV.

The results of these two studies were compared to data, information and assumptions associated with historical estimates of leak emissions (e.g., data referenced in the Subpart OOOOa TSD documents), and these comparisons indicate typical gas leak emissions for natural gas T&S facilities are less than historical estimates. These results and additional analyses suggest that the Subpart OOOOa LDAR leak survey frequency, delay of repair provisions, and leak definition are unnecessarily stringent and should be revisited. In addition, while not a focus of this paper, the

1 EPA-HQ-OAR-2010-0505-5120. "Background Technical Support Document for the Final New Source Performance Standards 40 CFR Part 60, subpart OOOOa," August 2015.

2 EPA-HQ-OAR-2010-0505-7631. "Background Technical Support Document for the Final New Source Performance Standards 40 CFR Part 60, subpart OOOOa," May 2016.

3 GHG Emission Factor Development for Natural Gas Compressors, PRCI Catalog No. PR-312-16202-R02, April 18, 2018.

4 "Air Resources Board RFP No. 13-414: Enhanced Inspection & Maintenance for GHG & VOCs at Upstream Facilities - Final (Revised)," Sage ATC Environmental Consulting LLC, Dec. 2016, available at https://www.arb.ca.gov/cc/oil-gas/sage_i&m_ghg_voc_dec2016.pdf.

results also indicate that emission factors (EFs) for the major compressor components developed by the PRCI study should replace annual Subpart W direct measurements for estimating compressor GHG emissions.

1.1 Overview of Natural Gas Leak Detection, Measurement, and Control

This section introduces some common terminology used throughout this paper that is associated with gas leaks and control requirements for natural gas T&S systems. Leaks from specific major compressor components have unique control and/or reporting requirements and are typically addressed separately from leaks from the population of other components within T&S facilities.

Major compressor components are specific seals and valves that have the potential to be sources of larger leaks. For centrifugal compressors, these include blowdown valves (gas leaked through the blowdown valve from a pressurized compressor is emitted from the compressor blowdown vent), unit isolation valves (when the compressor is de-pressurized, gas can leak from the pipeline side through isolation valves and be emitted through an open compressor blowdown valve), and wet seal oil degassing vents. Dry seals on centrifugal compressors are not considered a significant leak source. For reciprocating compressors, the primary leak sources include blowdown valves, unit isolation valves, and rod packing emissions. Subpart W requires emissions from these compressor sources to be measured, which typically involves direct measurement using flowmeters.

Component leaks, also referred to as "fugitive" emissions, are unintentional gas emissions from components that include, but are not limited to, valves, connectors, pressure relief devices (PRVs), open-ended lines (OELs), flanges, thief hatches or other openings on a storage vessel, instruments, and meters. Components are often further classified as being in compressor service or non-compressor service. Compressor components include those physically connected to or immediately adjacent to a compressor. Non-compressor components are all other components. A 1996 GRI/EPA natural gas system leak study (hereafter referred to as the "1996 GRI/EPA Study")5 found that compressor components leak gas at greater rates than non-compressor components. These higher leak rates were attributed to the unique design, size, and operation (e.g., thermal cycling) of some compressor components, as well as from the vibrational wear associated with compressors.

LDAR is the prescribed control strategy for component leaks. Leak surveys are conducted to detect gas leaks, and the leaks must be repaired in accordance with a prescribed schedule unless delay of repair provisions apply (e.g., a component cannot be safely repaired without shutting down the compressor). Leak surveys are typically conducted using optical gas imaging (OGI) or EPA Method 21. OGI employs infrared cameras to visualize gases invisible to the naked eye (e.g., methane), and any component with observed gas emissions is typically identified as a leaking component or "leaker." EPA Method 21 uses instruments to measure hydrocarbon concentrations (commonly referred to as screening values) in the vicinity of components in gas service, and components with SVs above a threshold are identified as leakers. Leaker threshold values of 500 or 10,000 ppmv are used in Subpart OOOOa and Subpart W, respectively. Neither OGI or Method 21 directly measure or quantify the gas leak emissions, and leaker mass emission rate versus SV data have considerable scatter. For example, historical data show that measured

5 Methane Emissions from The Natural Gas Industry, Volume 8: Equipment Leaks, GRI-

94/0257.25, EPA-600/R-96-080h, June 1996.

mass emissions from a leak with a given SV can vary by three or four orders of magnitude. After gas leaks are detected by OGI or Method 21, the leak rates can be directly measured by hi-volume sampler instruments.

1.2 Paper Content and Organization

Section 2 evaluates the impact of leak survey frequency and leak definition on LDAR control effectiveness. Section 3 summarizes some key findings of the PRCI report that analyzed Subpart W leak survey data and measurement data from major compressor components. The results of the CARB leak study are summarized in Section 4. Section 5 investigates the implications of the results of the PRCI report and the CARB study for T&S compressor station leak emission estimates and Subpart OOOOa requirements for leak survey frequency and leak repair schedules. Conclusions and implications are presented in Section 6.

2.0 Impact of Survey Frequency and Leak Definition on LDAR Control Effectiveness

40 C.F.R. § 60.5397a(g)(2) in Subpart OOOOa requires that all fugitive emissions components6 at covered natural gas compressor stations be monitored for gas leaks at least quarterly. Information provided by EPA in the final rule TSD indicates that EPA believes quarterly leak surveys using OGI will result in an 80% reduction in gas leak emissions.

"Data from the EPA (Leak) Protocol7 document estimates monthly Method 21 monitoring to achieve 87 percent reductions at a leak definition of 10,000 ppm and 92 percent reductions at a leak definition of 500 ppm. For quarterly monitoring, the Method 21 data from the EPA Protocol document estimates a 67 percent reduction at a leak definition of 10,000 ppm and an 83 percent reduction at a leak definition of 500 ppm. Using Method 21 data from the EPA Protocol document, we estimated the percent reductions from semiannual monitoring to be 55 percent at a leak definition of 10,000 ppm and 75 percent reduction at a leak definition of 500 ppm. The OGI camera is capable of viewing leaks at a 500 ppm level and achieve similar reductions as a Method 21 monitoring program. Based on this information, we believe the expected emission reductions from an OGI monitoring and repair program falls somewhere in the 500 and 10,000 ppm range found in the Method 21 monitoring programs. Therefore, it was estimated that an OGI monitoring program in combination with a repair program can reduce fugitive methane and VOC emissions from these segments by 40 percent on an annual frequency, 60 percent on a semiannual frequency and 80 percent on a quarterly frequency as well as minimize the loss of salable gas."

6 "Fugitive emissions component means any component that has the potential to emit fugitive emissions of methane or VOC at a well site or compressor station, including but not limited to valves, connectors, pressure relief devices, open-ended lines, flanges, covers and closed vent systems not subject to § 60.5411a, thief hatches or other openings on a controlled storage vessel not subject to § 60.5395a, compressors, instruments, and meters. Devices that vent as part of normal operations, such as natural gas-driven pneumatic controllers or natural gas-driven pumps, are not fugitive emissions components, insofar as the natural gas discharged from the device's vent is not considered a fugitive emission. Emissions originating from other than the vent, such as the thief hatch on a controlled storage vessel, would be considered fugitive emissions." 40 C.F.R. § 60.5430a.

7 EPA-453/R-95-017. "Protocol for Equipment Leak Emission Estimates," November 1995 (emphasis added), available at https://www3.epa.gov/ttnchie1/efdocs/equiplks.pdf.

"(TSD) Table 4-17. Percent Reduction in Emissions for EPA Method 21 Monitoring and Repair" Fugitive Percent Reduction (LDAR CE) Monitoring Frequency Method 21 Repair Threshold OGI 10,000 ppm 500 ppm Annual 42 68 40 Semi-annual 55 75 60 Quarterly 67 83 80

The LDAR control efficiencies (CEs) for OGI are not consistent with the statement in the TSD that "we believe the expected emission reductions from an OGI monitoring and repair program falls somewhere in the 500 and 10,000 ppm range found in the Method 21 monitoring programs."8 For example, the OGI annual CE is less than the 10,000 ppm CE. Also, the OGI semi-annual CE is close to the 10,000 ppm CE while the OGI quarterly CE is almost equal to the 500 ppm CE. In the TSD for the proposed rule, EPA assumed 40, 60, and 80% LDAR CEs for annual, semi-annual, and quarterly surveys based on a Colorado Air Quality Control Commission (CAQCC) Economic Impact Analysis.9 Stakeholder comments10 highlighted that the CAQCC values were based on a hypothetical scenario and not actual data. In the TSD for the final rule, the results in Table 4-17 showed identical CEs. It appears EPA essentially copied example calculations for a LDAR CE model from the EPA Leak Protocol in an attempt to support the unsupported CEs that were the basis for the proposed rule and associated the cost-effectiveness analyses. As discussed further below, these LDAR CE "modeling" results are not representative of CEs for natural gas compressor stations.

Thus, (1) the administrative record did not adequately justify the need for quarterly LDAR because the leak emissions reduction estimates were based on a LDAR CE model with high uncertainty and biased by flawed and unrepresentative data and assumptions. There is no evidence in the record showing that these reduction estimates were supported by actual measurements of gas leak emission reductions; and (2) more reliable actual leak measurement data from implementation of a multi-year oil and gas (O&G) systems directed inspection and maintenance (DI&M) program (i.e., repair larger leaks and those that are cost effective to repair) indicates that about 75 - 80% reduction is achieved using annual monitoring. Additional discussion follows.

(1) EPA's leak emissions reduction estimates are based on a LDAR control efficiency model with high uncertainty and biased by flawed and unrepresentative data and assumptions. These reduction estimates were not supported by actual measurements of gas leak emission reductions.

LDAR Control Efficiency Model Overview

The TSD used a LDAR CE model, and data and assumptions from the 1995 EPA Leak Protocol document to estimate the gas leak CEs for various leak definitions (i.e., Method 21 SVs) and

8 EPA-HQ-OAR-2010-0505-7631. "Background Technical Support Document for the Final New Source Perfor-mance Standards 40 CFR Part 60, subpart OOOOa," May 2016 at 42 (emphasis added).

9 Id. at 41.

10 See, e.g., INGAA Comments, Docket Document No. EPA-HQ-OAR-2010-0505-6872.

monitoring frequencies. These gas leak CEs are summarized in TSD Table 4-17. The EPA Leak Protocol acknowledges the limitations and uncertainty of this modeling by stating:

"The best way to calculate the effectiveness of an LDAR program is by collecting and analyzing data at the specific process unit."

and

"It should be noted that, to calculate the control effectiveness values presented in tables 5-2 and 5-3, assumptions were made that may not necessarily be applicable to specific process units."

The referenced "control effectiveness values presented in table 5-2," and the underlying LDAR CE model and associated data and assumptions are those used by EPA to calculate the gas leak CEs summarized in TSD Table 4-17. The following discussion and analysis demonstrates that the model input data and assumptions used by EPA are not representative of current T&S facilities, and that the EPA's gas leak CEs have a large uncertainty and a low bias.

Appendix 1 provides a detailed discussion that reviews the EPA Leak Protocol model, including associated equations and assumptions. A summary of that analysis indicates:

• The parameters and assumptions from Table 4-16 of the TSD that are CE model inputs are based on data that are about 40 years old (see Appendix G and Table G-3 in the EPA Leak Protocol)11,12 and are not representative of current operations that include a greater awareness of leaks and improved equipment and maintenance practices.

• The combination of non-representative process streams (i.e., leak Occurrence Rate data limited to leaks from 155 valves (84 in liquid service and 71 in gas service) at synthetic organic chemical manufacturing industry (SOCMI) plants (i.e., hydrocarbon process streams including some corrosive streams) rather than oil and natural gas operations with additional (i.e., other than valves) components),13,14 out-of-date equipment and operations, and dependence on valve data introduces bias that strongly suggests the leak Occurrence Rates (i.e., new leak formation rate) in TSD Table 4-16 are biased high relative to current T&S operations. The CE is very sensitive to the assumed Occurrence Rate.

• Leak Recurrence Rate (i.e., repaired sources for which a leak immediately recurs) is also based on the small 1980 study of valves at SOCMI plants,15,16 and the model assumes that the recurring leaks will occur instantly after the equipment is repaired and continue to leak until the next scheduled leak survey. Subpart OOOOa requires that leak repair is confirmed, and the Recurrence Rate should essentially be zero for leaking components subject to Subpart OOOOa.

11 EPA-450/3-82-010. "Fugitive Emission sources of Organic Compounds - Additional Information on Emissions, Emission reductions and Costs" April 1982.

12 EPA-600/S2-81-080. "Evaluation of Maintenance for Fugitive VOC Emissions Control" July 1981.

13 Id.

14 "SOCMI emission factors and correlations are applicable for estimating equipment leak emissions from the poly-mer and resin manufacturing industry." EPA-453/R-95-017. "Protocol for Equipment Leak Emission Estimates," November 1995 at 2-6, available at https://www3.epa.gov/ttnchie1/efdocs/equiplks.pdf.

15 EPA-450/3-82-010. "Fugitive Emission sources of Organic Compounds - Additional Information on Emissions, Emission reductions and Costs" April 1982.

16 EPA-600/S2-81-080. "Evaluation of Maintenance for Fugitive VOC Emissions Control" July 1981.

Additional assumptions associated with the "initial leak fraction" and average leak rate are also based on limited data from the 1980 SOCMI study17. In summary, leak emissions reduction estimates in the final rule's TSD were based on an LDAR CE model using flawed and unrepresentative data and assumptions, and the resulting CE estimates have a high uncertainty and are biased low - e.g., CE for annual surveys would be higher than the estimated in the TSD.

(2) More reliable actual leak measurement data from implementation of a multi-year O&G systems DI&M program indicates that about 75 - 80% reduction is achieved using annual monitoring.

A Canadian Association of Petroleum Producers (CAPP) 2014 report entitled "Update of Fugitive Equipment Leak Emission Factors"18 estimates that upstream oil and natural gas equipment leak emissions have decreased about 75% since DI&M best management practices (BMP)19 were implemented (in 2007 and later). For DI&M, leak rates are measured, and larger leaks and leaks that are cost-effective to repair are repaired. The 2014 CAPP report and BMP generally deem an equipment component to be leaking if it produces a SV of 10,000 ppm or greater when screened in accordance with Method 21, or if the emissions are detectable by OGI.

The BMP does not specify a leak detection survey frequency:

"Operators should develop a DI&M survey schedule that achieves maximum cost-effective fugitive emissions reductions yet also suits the unique characteristics and operations of their facility."20

However, the BMP does provide leak detection survey frequency guidance for various "leak-prone" equipment components. Annual surveys are recommended for control valves, block valves, emergency vents, PRVs, and OELs. Quarterly surveys are recommended for compressor seals and blowdown systems.21 Other components that are less "leak-prone," such as flanges and connectors, are likely surveyed annually or less frequently. Based on the BMPs, it seems that the majority of equipment components referenced in the CAPP report were surveyed annually, and CAPP determined that gas leak emissions from oil and natural gas equipment decreased approximately 75%. In other words, the CAPP report shows that an annual survey can achieve similar performance as EPA hypothesized could be achieved with quarterly surveys. Thus, annual surveys using a leak definition based on a Method 21 SV of 10,000 ppmv or OGI should provide the same level of leak emissions control that EPA sought to implement in the final rule. The Method 21 leak definition of 500 ppmv in Subpart OOOOa would be expected to marginally increase the level of control (albeit at a higher cost).

The CAPP report's finding that a 75% reduction in leak emissions can be achieved from oil and natural gas operations using annual monitoring and a DI&M approach for leak mitigation is based on multiple years of directly measured (e.g., by hi-volume sampler or flowmeter) and

17 Id.

18 EPA-HQ-OAR-2010-0505-4826. "Update of Fugitive Equipment Leak Emission Factors," Canadian Association of Petroleum Producers (CAPP), February 2014.

19 "Management of Fugitive Emissions at Upstream Oil and Gas Facilities," Canadian Association of Petroleum Producers (CAPP), January 2007.

20 Id.

21 Compressor seals (e.g., rod packing) are addressed separately in Subpart OOOOa and are not part of the LDAR requirements.

estimated (e.g., from Method 21 SVs and associated EFs) leak emissions. The CAPP report was the most reliable and best supported estimate of leak emissions reductions that IES found in its research, and these results are much more recent and representative of O&G systems than the data used by EPA for their LDAR CE model calculations. Rigorous LDAR programs, which require repair of all leaks (i.e., more leak repairs and nominally more reductions compared to a DI&M program), would be expected to have marginally higher reductions. Based on this CAPP data, an LDAR program with annual monitoring can reasonably be expected to have a CE of about 80% (albeit at a higher cost than DI&M).

Data were not found to assess how CE improves as survey frequency increases, but it is possible to estimate performance improvements with more frequent surveys. Leak reduction efficiencies for various typical leak monitoring frequencies can be estimated by assuming: (1) a linear leak rate growth with time (i.e., consistent with the EPA Leak Protocol LDAR CE model); (2) that all detected leaks are repaired; and (3) a leak emissions reduction efficiency of 80% for annual monitoring. Based on these assumptions, semiannual monitoring would incrementally reduce the annual monitoring emissions by half, for an overall annual control efficiency of 90% (incremental increase of 10% relative to annual monitoring - half of the remaining 20%). Similarly, quarterly monitoring would incrementally reduce the semi-annual monitoring emissions by another half, for an overall annual control efficiency of 95% (incremental increase of 5% relative to semiannual monitoring - half of the 10%). However, it may be more realistic to assume that quarterly monitoring might result in emission reductions of 90% because some repairs will need to be delayed because they are technically infeasible to repair during the designated timeframe, are unsafe to repair while the equipment is operating or would require a blowdown or shutdown.

The relatively small incremental reductions achieved by increasing the leak survey frequency are consistent with the leak survey monitoring frequency/reduction efficiency estimates calculated using the EPA Equipment Leaks Protocol LDAR CE model. Relative to a reduction of approximately 80% with annual surveys, estimates show relatively small incremental increases in emission reductions with more frequent surveys and indicate greatly diminished returns and lower cost-effectiveness when conducting leak monitoring more frequently than annually.

3.0 Review of Subpart W Leak Data and Emissions from PRCI Reports

This section summarizes results from the PRCI report22 that analyzed Subpart W data collected at natural gas T&S facilities from 2011 - 2016. These data include the results from:

• Leak rate measurements for major compressor components:

- Emission factors based on Subpart W measurements;

- The prevalence of components with large leak rates, and the impact of these large leaks on the emission factors;

- The prevalence of components with zero measured leakage:

- Relative average leak rates for the major compressor component; and

22 GHG Emission Factor Development for Natural Gas Compressors, PRCI Catalog No. PR-312-16202-R02, April 18, 2018.

- Estimated average facility leak emissions based on Subpart W measurements and historical EFs for natural gas T&S.

• Component leak detection surveys.

3.1 Leak Rates from Major Compressor Components

Subpart W of the Mandatory Greenhouse Gas Reporting Rule requires the direct measurement of natural gas leakage from major components on reciprocating and centrifugal compressors. As discussed in Section 1.1, the major compressor components are seals and valves with the potential to be larger sources of leak emissions and include blowdown valves (when the compressor is in either a "pressurized and operating" or "pressurized and standby" mode), unit isolation valves (when the compressor is in a "depressurized and idle" mode), rod packing on reciprocating compressors (when the compressor is in either a "pressurized and operating" or "pressurized and standby" mode), and wet seal degassing vents on centrifugal compressors (when the compressor is in either a "pressurized and operating" or "pressurized and standby" mode). The PRCI study23 compiled and analyzed over 14,000 Subpart W major component measurements collected from 2011-2016 on compressors in natural gas T&S service. These emissions data and supplemental data (e.g., compressor time in each mode) were collected from eleven PRCI member companies. The data set was vetted to eliminate acoustic instrument-based measurements with a demonstrated low bias, and a final data set of 10,637 reliable leak rate measurements was developed.

PRCI calculated Subpart W compressor EFs from these major compressor component measurements for each year from 2011 to 2016.24 These "Subpart W" EFs are presented in Table 3-1 and Figure 3-1, and compared to analogous US GHG Inventory EFs. Two sets of US GHG Inventory EFs are included: (1) EFs that were used to estimate leak emissions for years up to 2013 (2013-), which are presented in the inventory report published in 2015, and (2) EFs that were used to estimate leak emissions for years 2014 (i.e., presented in the inventory report published in 2016) and onward (2014+). The GHG Inventory changed these EFs after the 2013 inventory.

Generally, the Subpart W EFs are considerably less than the GHG Inventory (2013-) EFs and are comparable to the US GHG Inventory (2014+) EFs. The US GHG Inventory (2013-) EFs are based on the 1996 GRI/EPA Study and these results indicate leak emissions from major compressor components have decreased since the 1990s. These emission reductions are likely a result of improved seal and valve technology, and maintenance practices. Participation in the voluntary EPA Natural Gas STAR program may also have been a factor that led to lower emissions.

23 Id.

24 Compressor EFs are calculated by summing average measured leak rates for each major component/compressor mode combination weighted by the annual time fraction for each

mode. To provide comparability with the US GHG Inventory EFs, the time-in-mode fractions from the 1996 GRI/EPA report (Volume 8) were used. In addition, Subpart W does not require rod packing emission measurements when reciprocating compressors are in the pressurized and standby mode, and the US GHG Inventory EFs do include emissions from this mode. Thus, for comparability with the US GHG Inventory EFs, rod packing emissions in the pressurized and standby mode from the US GHG Inventory (2013-) EFs were added to the Subpart W emissions data used to develop the analogous Subpart W compressor EFs.

Table 3-1. Comparison of Subpart W and US GHG Inventory Compressor Emission Factors Emission Source scf CH4/compressor-day US GHG Inventory (2013-) 2011 2012 2013 US GHG Inventory (2014+) 2014 2015 2016 Subpart W avg Storage Reciprocating Compressor 17,464 6,400 7,410 11,491 9,957 19,745 12,169 14,241 11,909 Transmission Reciprocating Compressor 13,673 7,823 10,940 14,324 9,246 7,440 8,485 5,981 9,165 Transmission Centrifugal Compressor 42,106 6,270 7,773 7,411 9,673 6,382 8,015 3,382 6,539

Figure 3-1. Comparison of Subpart W and US GHG Inventory compressor emission factors.

When comparing the US GHG Inventory (2014+) EFs to Subpart W EFs, it is important to understand the difference in methodology. The study that provided the US GHG Inventory (2014+) EFs measured a very large leak from an isolation valve, but treated that data separate from the compressor EFs as a facility level "super emitter" contribution to the inventory. For the Subpart W EFs, some large leaks were measured and those measured values were included in the Subpart W EFs.

A prime driver of the magnitude of the Subpart W EFs calculated from the PRCI study is "high emitters" or "large leaks," which are infrequent but relatively large leaks. About 0.2% of the Subpart W major compressor component leaks (i.e., less than 20 of over 10,000 measurements)

0

5,000

10,000

15,000

20,000

25,000

30,000

35,000

40,000

45,000

Storage Reciprocating

Trans Reciprocating

Trans Centrifugal

Compressor EF (scfCH4/day)

Subpart W & US GHG Inventory Compressor EFs

US GHG Inventory (2013-)

2011

2012

2013

US GHG Inventory (2014+)

2014

2015

2016

Subpart W avg

had measured leak rates above 10,000 scf natural gas (NG)/hr). About 3% of the measured component leaks (285 measurements) were greater than 2,000 scf NG/hr (~7,750 metric tons CO2e per year, assuming 8,760 hours of operation and a methane global warming potential (GWP) of 25). The greater than 10,000 scf NG/hr leaks, while only about 0.2% of the total measured components, represent about 22% of the total gas leakage. The greater than 2,000 scf NG/hr leaks, about 3% of the total measured components, represent about 63% of the total gas leakage. The PRCI report includes Subpart W EFs developed after removing the 285 "large leak" measurements from the data set, and these "Subpart W (minus large leaks)" EFs are presented in Figure 3-2. Tabular presentation similar to the table above is available in the PRCI report. The overall 63% reduction in leakage emissions is reflected in the much lower EFs in Figure 3-2.

Figure 3-2. Comparison of Subpart W (minus large leaks) and US GHG Inventory compressor emission factors.

Subpart OOOOa regulates compressor seals separately from other leaks - e.g., via a prescribed rod packing maintenance interval. Figure 3-3 compares the Subpart W and US GHG Inventory (2013-) EFs for compressor seals. The Subpart W EFs for storage reciprocating compressor seals are generally greater than the US GHG Inventory (2013-) EF, and the average Subpart W EF is about 40% greater than the US GHG Inventory (2013-) EF. The Subpart W EFs for transmission reciprocating compressors are generally more comparable to the US GHG Inventory (2013-) EF, and the average Subpart W EF is about 20% greater than the US GHG Inventory (2013-) EF. The Subpart W EFs for centrifugal compressors are generally an order of magnitude lower than the US GHG Inventory (2013-) EFs. US GHG Inventory (2014+) EFs for compressor seals were not available. Figure 3-4 compares the Subpart W (minus large leaks) and US GHG Inventory (2013-) EFs for compressor seals, with the Subpart W (minus large leaks) EFs developed after removing the 285 "large leaks" measurements from the data set. The

0

5,000

10,000

15,000

20,000

25,000

30,000

35,000

40,000

45,000

Storage Reciprocating

Trans Reciprocating

Trans Centrifugal

Compressor EF (scf CH4/day)

Subpart W (minus large leaks) & US GHG Inv Compressor EFs

US GHG Inventory (2013-)

2011

2012

2013

US GHG Inventory (2014+)

2014

2015

2016

Subpart W avg

Subpart W (minus large leaks) EFs for storage reciprocating compressors are generally less than the US GHG Inventory (2013-) EF, and the average Subpart W (minus large leaks) EF is about 30% less than the US GHG Inventory (2013-) EF. The Subpart W (minus large leaks) EFs for transmission reciprocating compressors are generally more comparable to the US GHG Inventory (2013-) EF, and the average Subpart W (minus large leaks) EF is about 10% less than the US GHG Inventory (2013-) EF. The Subpart W (minus large leaks) EFs for centrifugal compressors are generally an order of magnitude lower than the US GHG Inventory (2013-) EFs. The storage data set is much smaller than the transmission data set, and large leaks generally had a more significant impact on the storage EFs. For example, about 67% of the Subpart W 2014 storage reciprocating compressor seal EF in Figure 3-3 was from emissions from a single compressor.

Figure 3-3. Comparison of Subpart W and US GHG Inventory emission factors for compressor seals.

0

2,000

4,000

6,000

8,000

10,000

12,000

14,000

16,000

18,000

Storage Reciprocating

Trans Reciprocating

Trans Centrifugal

Compressor EF (scf CH4/day)

Subpart W & US GHG Inv EFs for Compressor Seals

US GHG Inv (2013-)

2011

2012

2013

2014

2015

2016

Subpart W avg

Figure 3-4. Comparison of Subpart W (minus large leaks) and US GHG Inventory compressor seals emission factors.

PRCI also reviewed the Subpart W leak measurement data to determine the frequency of zero measurements - i.e., when the valve was not leaking. Figure 3-5 shows the Subpart W major compressor components with zero measured leakage from 2011 to 2016. The general trend is an increase with time for both the total number of zero measurements and the percent of the measurements that were zero. Figure 3-6 shows the Subpart W compressor seals with zero measured leakage from 2011 to 2016. No general increasing or decreasing trend is observed in Subpart W data, but this is not unexpected because those seals (e.g., rod packing) are intended to leak at a small rate even when new.25

25 See U.S. EPA, "Reducing Methane Emissions From Compressor Rod Packing Systems," EPA Natural Gas STAR Lessons Learned (Oct. 2006), https://www.epa.gov/sites/production/files/2016-06/documents/ll_rodpack.pdf.

0

2,000

4,000

6,000

8,000

10,000

12,000

14,000

16,000

18,000

Storage Reciprocating

Trans Reciprocating

Trans Centrifugal

Compressor EF (scf CH4/day)

Subpart W (minus large leaks) & US GHG Inv EFs for Compressor Seals

US GHG Inv (2013-)

2011

2012

2013

2014

2015

2016

Subpart W avg

Figure 3-5. Subpart W major compressor components with zero measured leakage from 2011 to 2016.

Figure 3-6. Subpart W compressor seals with zero measured leakage from 2011 to 2016.

An analysis of leak emissions within each sector can help identify leak mitigation opportunities. The voluntary EPA Methane Challenge Program and the TSD for the final rule (Section 7)26 focus exclusively on sources such as rod packing and wet seals. Figure 3-7 illustrates that according to data reported from 2011-2016 under Subpart W, isolation valves are the largest

26 EPA-HQ-OAR-2010-0505-7631. "Background Technical Support Document for the Final New Source Perfor-mance Standards 40 CFR Part 60, subpart OOOOa," May 2016.

0%

5%

10%

15%

20%

25%

30%

35%

40%

45%

0

100

200

300

400

500

600

700

800

900

1000

2011

2012

2013

2014

2015

2016

Percent of Total Count

Zero Count

Year

All Sources: Distribution of Zeros by Year

Zero Count

Zero Percent

0%

5%

10%

15%

20%

25%

30%

35%

40%

45%

0

100

200

300

400

500

600

700

800

900

1000

2011

2012

2013

2014

2015

2016

Percent of Total Count

Zero Count

Year

Seal Measurements: Distribution of Zeros by Year

Zero Count

Zero Percent

source of leaks. In addition, the lower emissions from blow down valve leaks (whether operating pressurized (BDOP) or standby pressurized (BDSB)) suggest that focusing on rod packing and isolation valves would result in significant leak reductions. Other facility leaks, reported through Subpart W as component leaks (valves, meters, connectors, etc.), are much smaller than compressor-related leaks from isolation valves, blowdown valves, reciprocating compressor rod packing and centrifugal compressor wet seal degassing vents. Leaks from these major compressor components account for 80-90% of facility leak emissions.

Figure 3-7. Major compressor component emission factors for Transmission and Storage.

PRCI evaluated "average" T&S facility leak emissions based on EPA US GHG Inventory EFs and Subpart W-based compressor EFs by comparing facility leak emission estimates based on:

(1) US GHG Inventory (2013-) EFs - data represented by the dark blue bar in Figure 3-8. These are historical leak EFs primarily from the 1996 EPA/GRI Study;

(2) US GHG Inventory (2014+) EFs - red bar data in Figure 3-8. These are leak emission estimates from an EDF/industry study conducted by Colorado State University (CSU study)[27] that bundle leaks emissions differently than the US GHG Inventory (2013-);

27 Zimmerle, et.al. (2015). Methane Emissions from the Natural Gas Transmission and Storage. Environ. Sci. Technol., 9374-9383.

0

50

100

150

200

Rodpacking or WetSeal - PressurizedOperating

Blowdown Valve -Pressurized Operating

Blowdown Valve -Pressurized Standby

Isolation Valve -Depressurized Idle

Component EF (scf CH4/hr)

Major Compressor Component EFs Based on 2011-2016 Subpart W Data

Transmission Reciprocating

Storage Reciprocating

Transmission Centrifugal

(3) US GHG Inventory (2014+) EFs + "super-emitters" - green bar data in Figure 3-8. The CSU study identified large leaks, (i.e., leaks classified as "super emitters")[28] and these are not included in the T&S station or compressor methane EFs used for the US GHG Inventory (2014+)[29]. These emission estimates are calculated by adding prorated super-emitter emissions to the above US GHG Inventory (2014+) EFs-based estimates;

(4) Subpart W Compressor EFs - purple bar data in Figure 3-8. These EFs do include all large leaks measured for Subpart W reporting (i.e., EFs from Figure 3-1); and

(5) Subpart W Compressor EFs (minus large leaks) - light blue bar data in Figure 3-8. These EFs are based on a program that mitigates the largest (< 3% by count) major compressor component leaks (i.e., EFs from Figure 3-2).

The CSU study[30] and US GHG Inventory (2014+) treated large leaks separately from station and compressor emission estimates, which differed from the Subpart W EFs development, so PRCI conducted a facility-level comparison using the five emission estimation approaches listed above to better address all leak sources and compare the estimation approaches. Subpart W EFs were adjusted to account for compressor source-mode combinations not measured, such as rod packing emissions in pressurized and standby mode. Figure 3-8 presents the average facility-level leak emissions, and the data show:

• significantly lower emissions for the 2011 - 2016 composite Subpart W data and the US GHG Inventory (2014+) relative to the US GHG Inventory (2013-). These data indicate about a 50% reduction in T&S leak emissions over the last 20 to 25 years since the 1996 EPA/GRI study was conducted; and

• that mitigating larger leaks (which comprise less than 3% of total leaks by count) can result in substantial additional emission reductions. Facility leak emissions using Subpart W Compressor EFs (minus large leaks) were reduced approximately 37% relative to the Subpart W Compressor EFs data and about 70% relative to the US GHG Inventory (2013-). This 70% reduction is similar in magnitude to the LDAR CE assumed in the TSD and, similar to the DI&M data discussed in Section 2, suggests that focusing on controlling large leaks can produce substantial emission reductions.

For component leaks other than major compressor components (i.e., components subject to the LDAR provisions in Subpart OOOOa), the Subpart W emission estimate is based on leak survey results and Subpart W component-specific leaker EFs and comprises less than 20% of the total leak emissions.

28 Id.

29 E.g., refer to TableA-137 of "Annexes to the Inventory of U.S. GHG Emissions and Sinks," available at https://www.epa.gov/sites/production/files/2017-04/documents/us-ghg-inventory-2016-annexes.pdf.

30 Id.

Figure 3-8. Comparison of Average Facility Leak Emissions Based on US GHG Inventory EFs versus Subpart W-based compressor EFs.

The PRCI study provides over 10,000 new measurements and offers the ability to use contemporary measurements and supplemental data to better estimate T&S leak emissions from major compressor components. As shown above, the compressor emissions from 2011-2016 Subpart W reporting data are much lower than historical data and indicate that the main source of leak emissions are isolation valves and reciprocating compressor rod packing.

3.2 Subpart W Component Leak Detection Surveys

In addition to leak rate measurement for major compressor sources, Subpart W requires counts of leaking components for the balance of the facility based on an annual leak survey. Leaker EFs are then used along with component-level leak counts to estimate emissions. For transmission compressor stations, Subpart W further segregates the components into compressor or non-compressor service. Table 3-2 summarizes the results of the Subpart W leak surveys for T&S facilities for the years 2011 - 2016. On average, the data show approximately 10 to 25 leaking components per facility. The emissions per leak are generally low when compared to the major compressor sources discussed above (e.g., rod packing, isolation valves, blowdown valves). Section 4 discusses results from a recent CARB report that suggests that component-level EFs may be lower than historical estimates (e.g., the Subpart W leaker EFs).

-

5,000

10,000

15,000

20,000

Transmission

Storage

T&S Composite

Facility Average Leak Rate (mt CO2e)

US GHG Inv (2013-)

US GHG Inv (2014+)

US GHG Inv (2014+) + "Super Emitter"

Subpart W Compressor EFs

Subpart W Compressor EFs (minus large leaks)

Table 3-2. Subpart W Component Leak Survey Results

2011

2012

2013

2014

2015

2016

Transmission (average number of leaking components per station)

NC - Meter

0.0

0.0

0.0

0.1

0.2

0.2

NC - PRV

0.3

0.2

0.3

0.2

0.4

0.3

NC - OEL

0.8

0.8

1.0

1.0

1.4

1.4

NC - Connector

2.1

2.2

5.5

3.3

5.2

3.6

NC - Gas Service Valve

2.4

2.1

4.0

3.0

3.6

3.3

C - Meter

0.0

0.0

0.0

0.1

0.1

0.0

C - PRV

0.2

0.3

0.4

0.1

0.2

0.2

C - OEL

0.5

1.0

0.6

0.6

0.9

0.7

C - Connector

3.7

3.1

7.4

2.7

5.0

3.0

C - Valve

2.8

3.0

4.8

2.6

3.5

2.6

Storage Stations (average number of leaking components per station)

Meter

11.8

0.2

0.7

0.4

0.2

0.5

PRV

0.2

0.2

0.5

0.2

0.4

0.8

OEL

0.2

0.4

1.9

2.3

1.5

1.9

Connector

8.4

7.4

10.8

7

9.9

7.5

Valve

5.8

9.2

10.5

7.4

8.1

7.6

4.0 CARB Measurements of Leaks from Components in Natural Gas Service

40 C.F.R. § 60.5397a(a) in Subpart OOOOa defines fugitive emissions (i.e., a gas leak) at a compressor station as "Any visible emission from a fugitive emissions component observed using optical gas imaging or an instrument reading of 500 ppm or greater using Method 21." Emissions from gas leaks with EPA Method 21 SVs of 500 ppmv may be extremely low. A recent CARB leak measurement study measured Method 21 SVs and mass emission rates from leaking components in natural gas service.31 The study developed leak rate/SV correlation equations for five different component types (i.e., valves, connections, flanges, OELs, and others (e.g., regulators, meters, controllers)), with the correlations providing an average leak rate for the component type as a function of the Method 21 SV. As noted above, historical data show that measured mass emissions from a leak with a given SV can vary by several orders of magnitude.

Table 4-1 estimates average emission rates from components in natural gas service using these correlations and Method 21 SVs of 500; 1,000; 10,000; 50,000; and 100,000 ppmv. These correlations indicate that an average 500 ppmv leak emits less than one cubic foot of gas per year. As shown in Table 4-1, average emissions from a 10,000 ppmv leak are low, less than 20 scf/year of gas valued at less than ten cents. The CARB study was limited in scope as indicated by the following statement from the report:

"The measurements collected in this study were meant to fill in a matrix in order to develop a correlation equation and not for the development of emission factors. As

31 "Air Resources Board RFP No. 13-414: Enhanced Inspection & Maintenance for GHG & VOCs at Upstream Fa-cilities - Final (Revised)," Sage ATC Environmental Consulting LLC, Dec. 2016, available at https://www.arb.ca.gov/cc/oil-gas/sage_i&m_ghg_voc_dec2016.pdf.

such, they do not account for super-emitters, and once the matrix was full, any additional leaks detected were discarded."

Thus, for example, while the correlation equations provide estimates of average gas leak rates associated with a SV of 10,000 ppmv, these estimates are not comparable to an EF that included leaks with SVs of 10,000 and greater. An EF that includes leaks with higher SVs may include some very large leaks and those leaks could dominate the EF (i.e., the average measured leak rate). This is discussed further below and is demonstrated in Figure 4-2. However, the correlation equations do provide an indicator of the trivial nature of typical leaks at SVs commensurate with common leak definitions (e.g., 500 ppmv in Subpart OOOOa and 10,000 ppmv in Subpart W).

Table 4-1. Gas Leak Rate Estimates for Components in Natural Gas Service with Method 21 Screening Values of 500 to 100,000 ppmv32

M21 SV (ppmv)

Average Component Leak RateA (TOC as CH_4)

kg/hr

g/day

lb/yr

mt CO_2e/yr

scf/hr

scf/yr

$ NG/yr

500

5.4E-7

0.01

0.01

0.0001

2.8E-5

0.2

$0.001

1,000

1.4E-6

0.03

0.03

0.0003

7.2E-5

0.6

$0.002

10,000

4.1E-5

0.99

0.79

0.009

2.1E-3

18.8

$0.06

50,000

5.1E-4

12.24

9.85

0.11

2.7E-2

233.0

$0.80

100,000

1.6E-3

37.31

30.03

0.34

8.1E-2

710.2

$2.44

A. Values are the average of the correlation calculated average leak rates for valves, connections, flanges, OELs, and others

32 CO2e emissions in all tables and discussion based on a methane GWP of 25 and natural gas valued at $3.44 per Mcf.

Figure 4-1 graphs the correlation equations from the CARB report for the five component types on a log-log scale.

Figure 4-1. Leak rate versus Method 21 SV correlation equations by component type (log-log scale).

The CARB correlations can be further analyzed by plotting leak rate correlations on a linear y-axis rather than a log scale, as shown in Figure 4-2. Figure 4-2 does not show actual measured data points, but rather the estimated average emission rate at different concentration SVs based on the correlation equations. The figure illustrates the very low gas leak rates associated with Method 21 SVs below 50,000 ppmv, and how a small number of high leak rates in a leaking components data set could dominate an associated EF. Because leak rates can vary significantly (i.e., by several orders of magnitude), estimating leak emissions based on leaker EFs or correlation equations is fraught with uncertainty.

1.0E-9

1.0E-8

1.0E-7

1.0E-6

1.0E-5

1.0E-4

1.0E-3

1.0E-2

1.0E-1

10

100

1,000

10,000

100,000

Estimated Average Emissions (kg/hr)

Screening Value (ppmv)

Valves

Connectors

Flanges

OELs

Other

Figure 4-2. Leak rate versus Method 21 SV correlation equations by component type (log-linear scale).

Finally, while direct comparison between emission rates from correlation equations and average EFs is complicated, it can provide some insight into relative emissions from different data sources. In comparison to the leaker EFs in Subpart W, the CARB correlation equations imply significantly lower emissions for most leaks. The Subpart W component-level leaker EFs range from approximately 1 to 40 scf of total hydrocarbon per hour33 which is equivalent to about 0.02 to 0.75 kg/hr. Thus, the Subpart W EFs are significantly higher than the emission rates from the CARB data as shown in the y-axis scale in Figure 4-2 (i.e., maximum y-axis scale in Figure 4-2 is 0.002 kg/hr).

5.0 Implications of the PRCI / Subpart W and CARB Study Results for Subpart OOOOa Leak Emission Estimates and Mandated Repair Schedule Provisions

This section discusses the implications of the results of the PRCI/Subpart W and CARB studies for (1) the T&S facilities gas leak emission estimates that were the basis for Subpart OOOOa fugitive leak emission provisions, and (2) the Subpart OOOOa mandated gas leak repair schedule provisions.

5.1 Revised Estimates of Subpart OOOOa T&S Model Plant Emissions Based on PRCI / Subpart W and CARB Studies Data

The Subpart OOOOa TSD employed "model plants" to estimate the cost-effectiveness of LDAR for fugitive emissions from non-compressor components at T&S natural gas compressor stations. The TSD model plants were based on component counts and methane EFs for non-compressor components obtained from the 1996 EPA/GRI Study. EPA calculated methane emissions for these model plants by multiplying the model plant component counts by the component methane

33 See Subpart W, Tables W-3A and W-4A (methane default in 0.975 in section 98.233(q), Equation W-30).

0.0000

0.0005

0.0010

0.0015

0.0020

10

100

1,000

10,000

100,000

Estimated Average Emissions (kg/hr)

Screening Value (ppmv)

Valves

Connectors

Flanges

OELs

Other

EF. Figure 5-1 presents the TSD model plant estimates, labeled as "OOOOa TSD," for transmission and storage. The total storage plant emissions include Storage Station emissions and Storage Wellhead emissions. Figure 5-1 also presents comparative emission estimates for these model plants based on more recent information presented in the preceding sections:

• "Sub W Count & Non-compressor Leaker EFs." Transmission and Storage Station emission estimates are based on the average number of leaking components, by component type, measured at compressor stations during the Subpart W leak surveys (see Table 3-2) and associated Subpart W non-compressor leaker EFs (see Table W-3A of Subpart W). Storage Wellhead emission estimates are based on the average population of components, by component type, counted at Storage Wellheads during Subpart W surveys and associated Subpart W population EFs (see Table W-4B of Subpart W).

• "Sub W Count & CARB Leaker EFs for SV = 50,000." Transmission and Storage Station emission estimates are based on the average number of leaking components, by component type, measured at compressor stations during the Subpart W leak surveys (see Table 3-2) and associated CARB leaker EFs based on a SV of 50,000 ppmv and the CARB study leak rate/SV correlations (see Figure 4-2). Screening values for leaking components are not reported under Subpart W; thus, IES has assumed a conservative average SV of 50,000 ppm. Storage Wellhead emissions were estimated as described above.

Figure 5-1. Estimated CH4 leak emissions based on various component count and emission factor data for Transmission model plants and Storage model plants.

The emissions in Figure 5-1 are presented as tons per year of methane rather than CO2e emissions. For context, the Subpart OOOOa TSD emission estimate of 40 TPY methane (green bar) is equivalent to 1,000 TPY CO2e emissions. When compared to the facility average leak emissions in Figure 3-8, it is evident that estimated leaks from facility components other than the major compressor sources are relatively minor. For the Transmission model plant, the estimated methane emissions based on the OOOOa TSD are about a factor of 4 greater than the estimated methane emissions based on the Sub W Count & Non-compressor Leaker EFs. The estimated

0.0

40.0

80.0

120.0

160.0

OOOOa TSD

Sub W Count &Non-compressorLeaker EFs (A)

Sub W Count &CARB LeakerEFs for SV =50,000 (A)

Avg Facility CH4 Leak Emissions (tpy)

Facility Leak Estimate Data Source

Transmission

Storage Wellhead

Storage Station

A. Wellheademissions estimated using Sub W population EFs

methane emissions for the Transmission model plant based on the "Sub W Count & CARB Leaker EFs for SV = 50,000" are negligible. For the Storage model plant Storage Station components, the estimated methane emissions based on the OOOOa TSD data are about a factor of 5 greater than the estimated methane emissions based on the "Sub W Count & Non-compressor Leaker EFs," and the estimated methane emissions based on the "Sub W Count & CARB Leaker EFs for SV = 50,000" are negligible. The significantly lower emission estimates, for both the Transmission and Storage Station model plants, based on the Sub W Count & Non-compressor Leaker EFs suggest non-compressor component leak emissions have decreased since the TSD model plant data were collected in 1992. That is, the Subpart OOOOa TSD model plant data are not representative of current natural gas operations that include a greater awareness of leaks and improved equipment components and maintenance practices.

As discussed in Section 4.0, direct comparisons between the CARB correlation equations and the Subpart W leaker EFs are not straightforward but can provide insight. The CARB leak rate/SV correlation equations are based on a relatively small data set, and the measurements were not intended to develop EFs. The Subpart W leaker EFs are based on older data that comprise a much larger data set with a wide range of measured leak rates. In either case, the leak estimates from facility components are relatively minor compared to the leak estimates from measured data (e.g., compare leak rates in Figure 5-1 to section 3 leak rates).

While not a primary focus of this paper, Figure 5-1 also presents storage wellhead emission estimates. For the Storage model plant Storage Wellhead components, the estimated methane emissions based on the TSD are about 10% of the estimated methane emissions based on the Subpart W storage wellhead component counts (i.e., "Sub W Count & Non-compressor Leaker EFs" and "Sub W Count & CARB Leaker EFs for SV = 50,000"). All three estimates use population EFs; however, the Subpart W/actual wellhead component counts were about 10 times the component counts assumed for the OOOOa TSD model plant.

5.2 Subpart OOOOa Mandated Gas Leak Repair Schedule Provisions Should Consider that Typical Leak Rates are Very Small

The leak rate versus Method 21 SV data and correlations presented in Section 4 demonstrate that most leaks, particularly those with SVs of 10,000 ppmv or less, emit gas at a very small rate. If a leak cannot be immediately repaired (i.e., after detection during a LDAR leak survey), then the Subpart OOOOa LDAR mandated repair schedule could require site actions that would result in significantly more GHG emissions than an unrepaired leak. Unless delay of repair provisions apply, 40 C.F.R. § 60.5397a(h)(1) requires that:

"…each identified source of fugitive emissions shall be repaired or replaced as soon as practicable, but no later than 30 calendar days after detection of the fugitive emissions."

40 C.F.R. § 60.5397a(h)(1) allows delaying a repair in circumstances where equipment must be blown down (i.e., depressurized by releasing the natural gas to the atmosphere) to safely repair a leaking component.

"If the repair or replacement is technically infeasible, would require a vent blowdown, a compressor station shutdown, a well shutdown or well shut-in, or would

be unsafe to repair during operation of the unit, the repair or replacement must be completed during the next scheduled compressor station shutdown, well shutdown, well shut-in, after a planned vent blowdown or within 2 years, whichever is earlier."

By allowing a repair to be delayed if a vent blowdown would be required to safely repair the leak, the rule logically accounts for situations where repairing the leaking component may result in greater emissions than allowing the leak to continue until a previously scheduled shutdown. This same logic should apply when considering the environmental impact of actions such as unscheduled travel necessary to comply with Subpart OOOOa leak repair schedule requirements (e.g., vehicular travel specifically to acquire parts and/or make repairs outside of the normal maintenance schedule).

For example, consider the emissions associated with making a repair if a "unique vehicle trip" is required. A light duty truck emits about one pound of CO_2 per mile.[34] Based on the correlations from the CARB study, it would take about 18 days for an "average" 10,000 ppmv leak to emit one pound of CO_2e. Table 5-1 compares the emissions from an average natural gas leak to those from vehicle emissions associated with actions necessary to repair a leak within a defined timeframe. The comparison assumes a relatively short drive of ten miles whereas a unique round trip to a remote compressor station could be an order of magnitude longer.

The vehicle CO_2e emissions associated with a ten-mile trip is equivalent to about 184 days of emissions from an average natural gas leak with a 10,000 ppmv SV. For an average leak with a 500 ppmv SV (the Subpart OOOOa leak definition includes a Method 21 SV of 500 ppmv or greater), the equivalent time is about 38 years. The "equivalent times" from these examples illustrate that repairing small natural gas leaks outside of the normal maintenance schedule and procedures (e.g., requiring a vehicular trip for parts or specialized staff to commute to the site) would likely result in a net GHG emissions increase.

Table 5-1. Comparison of Vehicle Trip GHG Emissions to "Average" Leak Rate from CARB Study

Vehicle emissions (lb CO_2e/mi)A	Mileage assumed	Vehicle emissions (lbs CO_2e)	Leak Screening Value (ppmv)	Average EmissionsB (lbs CO_2e / day)	Equivalent time (days)C
1.0	10	10.0	10,000	0.054	184
1.0	10	10.0	500	0.00072	14,000
1.0	10	10.0	10,000	0.010B	1,000

A Approximate emissions from gasoline light duty truck.

B Average emissions based on CARB report correlation of emission rate as a function of Method 21 SV. The first two rows use the weighted emission factor for all component types. The third example uses the emission factor for a leaking connector or flange, which is the most common leak source.

C "Equivalent time" is the number of days required for the leaking component CO_2e mass emissions to be equivalent to the emissions from a 10-mile trip with a light duty truck.

34 Based on CO_2 emissions from motor gasoline combustion of 20 pounds per gallon, with the truck averaging about 20 mpg. See U.S. Energy Information Administration, https://www.eia.gov/tools/faqs/faq.php?id=307&t=11 (burning a gallon of diesel fuel produces about 22.4 pounds of CO_2, whereas burning a gallon of pure gasoline produces 19.6 pounds of CO_2. Burning a gallon of gasoline that contains 10% ethanol produces about 17.6 pounds of CO_2.)

Cost-effectiveness is also a consideration for mandatory leak repair schedules. For example, the incremental emissions associated with repairing an average 10,000 ppmv leak after 90 days (e.g., consistent with a quarterly maintenance schedule) rather than 30 days is about 3.3 lbs (or 0.0015 metric tons) of CO_2e (based on a GWP of 25 for methane). If an operator was required to make a designated trip to repair the leak to meet a repair schedule, and the repair required one hour at $60/hr, the cost-effectiveness associated with the incremental leak reduction would be about $40,000 per metric ton CO_2e, which is a very high value for GHGs. Further, and as discussed above and shown in Table 5-1, a light duty truck emits about one pound of CO_2 per mile. Thus, if the designated trip to repair the leak to meet the repair time period required more than 3.3 miles of driving, compliance with the rule would cause a net increase in GHG emissions.

These data indicate that allotted repair time periods for most leaks should be of sufficient duration that repairs can be conducted during a normal and organized repair schedule that would not require unnecessary site visits (i.e., driving) or other extraordinary effort that will result in excess GHG emissions, as well as to avoid extremely disproportionate costs relative to the incremental emission reductions. Rather than requiring that all repairs be made within 30 days (except those that may be delayed), completing repairs at the next scheduled process shutdown for maintenance may be appropriate in most cases.

6.0 Conclusions and Implications

New data and reports provide improved estimates of T&S facility leak emissions, and a better understanding of mitigation opportunities and LDAR performance. The following list summarizes the conclusions and implications presented in this paper regarding the current Subpart OOOOa requirements that pertain to fugitive emissions from T&S compressor stations.

- The current requirement in Subpart OOOOa to conduct quarterly fugitive emission surveys for T&S facilities is not supported by the TSD with data from natural gas facilities, but rather was based on assumptions and a LDAR CE model using data and reports from a limited chemical plant study that is more than 30 years old. Section 2 and Appendix 1 discuss this TSD model in more detail.

• A Canadian (CAPP) study conducted at oil and gas facilities indicates that annual surveys at T&S facilities can achieve leak mitigation control efficiency commensurate with the assumptions made in the TSD for quarterly surveys. The multi-year CAPP study shows that this control efficiency can be achieved by repairing larger leaks and those that are cost effective to repair (i.e., using directed inspection and maintenance) rather than conventional LDAR which requires the repair of all leaks.

• A PRCI report compiled over 10,000 measurements of primary leak sources for T&S reciprocating compressors and centrifugal compressors conducted from 2011 - 2016 at facilities subject to Subpart W. Emission estimates and emission factors based on these data show that compressor leak emissions are significantly lower than historical estimates. This dataset is more indicative of current operations than data or reports from decades ago.

• The PRCI Subpart W emissions data show that isolation valves and reciprocating compressor rod packing are the primary sources of leak emissions at T&S facilities.

• Direct comparison of leak emission estimates from different studies or programs is complicated by different integration of results, such as how large leaks (or "super emitters")

are accounted for in the inventory. However, reasonable estimates that compare average facility emissions show significantly lower emissions based on more current data as compared to historical estimates.

• A recent CARB study provides correlation equations for estimating leak emissions from facility components other than the primary compressor leak sources. Historical data indicate that these facility components leak emissions are typically less than 20% of total facility leak emissions. The CARB data indicates that these leak emissions may be more than an order of magnitude lower than historical estimates. This finding highlights the inefficiency associated with LDAR programs that require control of all leaks with leak definitions including a 500 ppmv Method 21 screening value threshold or any leak visible with optical gas imaging.

• Because most leak rates are small, the environmental harm associated with LDAR repair requirements should be taken into consideration in Subpart OOOOa. Operators should not be required to engage in separate vehicular travel to repair a small leak. Such repairs should be made during the next scheduled shutdown for maintenance.

• Because recent data and reports indicate leak emissions are actually lower than historical estimates, the potential emission reductions possible from the T&S sector are likely over-estimated by the Subpart OOOOa TSD. If the predicted emissions have been over-estimated, the LDAR cost benefit analysis in the Subpart OOOOa TSD is likely inaccurate. The cost of compliance would be reduced, however, if the frequency of conducting fugitive emissions surveys is modified from quarterly to annually.

• While not a focus of this paper, the PRCI analysis of over 10,000 measurements completed for Subpart W annual surveys provides emission factors for reciprocating compressors and centrifugal compressors. Those emission factors should be used to: (1) improve the annual US GHG Inventory for T&S; and (2) replace Subpart W annual measurements with emissions estimates based on compressor emission factors.

Appendix 1:

Review of EPA Leak Protocol Methodology and Assumptions

for Estimating LDAR Control Efficiency

Equations 1 - 4 summarize the EPA Leak Protocol LDAR CE model. Additional detail and explanation can be found in Section 5.3 of the EPA Leak Protocol.

$Y_i = Z_i - (FR \times Z_i) + (FR \times Z_i \times R)$ Eqn. 1

Where:

Y_i

=

Leak fraction immediately after monitoring cycle i

Z_i

=

Leak fraction immediately preceding monitoring cycle i (Z_1 is the initial leak fraction)

FR

=

Fraction of leaking sources successfully repaired

R

=

Fraction of repaired sources for which a leak immediately recurs

$Z_{i+1} = O_c \times (1 - Y_i) + Y_i$ Eqn. 2

Where:

Z_{i+1}

=

Leak fraction immediately preceding monitoring cycle i+1

O_c

=

Fraction of non-leaking sources which will leak in the time-period between monitoring cycles. The "occurrence rate" is the fraction of components that were not leaking at the start of the time-period between monitoring cycles and are leaking at the end of the time period between monitoring cycles. The model assumes a linear leak growth rate.

Y_i

=

Leak fraction immediately after monitoring cycle i

After several monitoring cycles, the leak frequency will be found to approximately oscillate between points Y_i and Z_i. The average value of these two "steady-state" values is the final leak fraction. This leak fraction and the initial leak fraction (i.e., Z_1) are entered into an applicable leak fraction/leak mass rate correlation equation (i.e., "Average Leak Rate Equation" in TSD Table 4-16 reprinted below) to calculate leak mass rates at these leak fractions, and then input into Equation 3 to estimate the LDAR CE.

$Eff = (ILR - FLR)/ILR \times 100$ Eqn. 3

Where:

Eff

=

LDAR control effectiveness (percent)

ILR

=

Initial leak rate (kg/hr/source)

FLR

=

Final leak rate (kg/hr/source)

Equation 3 applies for a single component type. If more than one component type is surveyed, then the initial and final leak fractions need to be determined for each component and then input into Equation 4 to estimate the total LDAR CE.

□□□=Σ□□□□□□=1-Σ□□□□□□=1Σ□□□□□□=1□ 100 Eqn. 4

Where:

Eff

=

LDAR control effectiveness (percent)

ILRi

=

Initial leak rate for component i (kg/hr/source)

FLRi

=

Final leak rate for component i (kg/hr/source)

n

=

Number of component types

Data and Assumptions Used to Calculate LDAR Control Efficiencies

Table 4-16 from the TSD summarizes the data and assumptions used as model inputs in the TSD to calculate LDAR CE estimates.

"(TSD) Table 4-16. Parameters and Assumptions Used to Calculate Monitoring Cycles"

Parameter

Parameter Value (500 ppm)

Parameter Value

(10,000 ppm)

Occurrence Rate (Oc)

5.46% Annual,

4.21% Semiannual,

2.97% Quarterly

5.46% Annual,

4.21% Semiannual,

2.97% Quarterly

Recurrence Rate (R)

14%

14%

Unsuccessful Repair Rate (UR)

- FR = 1 - UR

10%

10%

Initial Leak Fraction (Z1)

13.53%

7.49%

Average Leak Rate (ALR) Equation

ALR = 0.044*Leak Fraction (LF) + 0.000017

ALR = 0.078*LF + 0.00013

These parameters and assumptions are based on data that are about 40 years old (see Appendix G and Table G-3 in the EPA Leak Protocol)[35,36] and are not representative of current O&G operations that reflect a much greater awareness of natural gas leaks and associated improved equipment components and maintenance practices.

1. The leak Occurrence Rates (i.e., new component leaks) are assumed to be linear over the associated time-period and are based on a very small study of valves (155 total valves, 84 in liquid service and 71 in gas service) at SOCMI plants (i.e., hydrocarbon process streams). This study was conducted in 1980 (i.e., about 40 years ago). These organic chemical production plants include corrosive process streams that are not representative of O&G process streams. In addition, only leak data for valves (71 in gas service) was used to estimate these occurrence rates, and because valves have seals and moving parts, they

35 EPA-450/3-82-010. "Fugitive Emission sources of Organic Compounds - Additional Information on Emissions, Emission reductions and Costs" April 1982.

36 EPA-600/S2-81-080. "Evaluation of Maintenance for Fugitive VOC Emissions Control" July 1981.

develop more leaks than static components such as connectors (i.e., valve leak occurrence rate > leak occurrence rate for all components). The combination of non-representative (i.e., non-O&G) process streams, out-of-date equipment and operations, and valve data bias strongly suggests the Occurrence Rates in TSD Table 4-16 are biased high relative to current O&G operations.

A high bias in the Occurrence Rate would cause an under-estimation of the LDAR CE. Figure A-1 shows the impact of the Occurrence Rate on the CE calculation. For example, for annual surveys and a 10,000 ppmv leak threshold, changing the leak occurrence rate assumption from 5.5% to 4% to 2.5% increases CE from 42% to 57% to 72%. The high sensitivity of the CE calculation to the Occurrence Rate, and to other model input parameters and assumptions with large uncertainties, imparts a large uncertainty in the CE calculations.

Figure A-1. LDAR control efficiency vs. leak Occurrence Rate

2. The Recurrence Rate is also based on the small 1980 study of valves at SOCMI plants,[37,38] and the model assumes that recurring leaks occur instantly after the equipment is repaired and continue to leak until the next scheduled leak survey. These recurrence rates do not apply to current O&G operations because: (1) the leak repair was limited to tightening the bolts on the valve packing gland (i.e., more extensive repairs such as replacing the packing gland were not attempted), and (2) Subpart OOOOa requires that a repaired component be resurveyed to verify the leak has been adequately repaired [40 C.F.R. § 60.5397a(h)(3)] (i.e., a "recurring" leak would be repaired soon after the initial repair attempt). In sum, the Recurrence Rates in TSD Table 4-16 are biased high relative to current O&G operations, and a value of zero would be a reasonable estimate.

37 EPA-600/S2-81-080. "Evaluation of Maintenance for Fugitive VOC Emissions Control" July 1981.

38 EPA-450/3-82-010. "Fugitive Emission sources of Organic Compounds - Additional Information on Emissions, Emission reductions and Costs" April 1982.

0

10

20

30

40

50

60

70

80

90

100

0

1

2

3

4

5

6

7

8

Control Efficiency (%)

Leak Occurrence Rate (%)

LDAR Control Efficiency vs. Leak Occurrence Rate

10,000 ppm Annual

10,000 ppm Quarterly

500 ppm Annual

500 ppm Quarterly

3. The Unsuccessful Repair Rate is based on studies conducted in the 1970s and early 1980s at SOCMI plants and refineries.39 Subpart OOOOa does allow repairs to be delayed for components that are unsafe to repair while the equipment is operating, are technically infeasible to repair within the designated timeframe, or would require a blowdown or shutdown. Such components would have the same impact on the LDAR CE calculation as the Unsuccessful Repair Rate. Thus, a non-zero value for the model is reasonable.

4. The Initial Leak Fraction is based on a combined screening data set for SOCMI plants from the EPA Leak Protocol. These data are over 30 years old. The combination of non-representative (i.e., non-oil and natural gas) process streams and out-of-date

equipment and operations suggests these Initial Leak Fractions are biased high relative to current T&S operations.

5. The Average Leak Rate Equations are derived from the average leak rate of valves above the leak definition, the average leak rate of valves below the leak definition, and the fraction of valves with leak rates above the leak definition (i.e., the Leak Fraction). These Average Leak Questions are based on leak measurements for valves at SOCMI plants, and their applicability for components at O&G systems is unknown.

In sum, the EPA's leak emissions reduction estimates are based on a LDAR CE model using flawed and unrepresentative data and assumptions, and the resulting LDAR CE estimates have a high uncertainty and low bias.

39 EPA-450/3-82-010. "Fugitive Emission sources of Organic Compounds - Additional Information on Emissions, Emission reductions and Costs" April 1982.